APPENDIX H

EROSION AND SEDIMENTATION

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Baseline knowledge of soil erosion and the subsequent transport and deposition of eroded sediment into streams and other water bodies is essential to mine planning and operation. Accurate measurement of natural erosion and erosion from disturbed areas is important to develop control practices. Significant environmental impacts, such as the irretrievable loss of soil, or the degradation of aquatic life from the sedimentation of streams, lakes, wetlands, or marine estuaries, can be minimized or prevented by employing control practices. The measurement and prediction of the amounts of erosion and sedimentation is inherently tied to the measurement and prediction of site hydrologic variables such as precipitation, runoff, and stream flow. An outline and comparison of methods, analytical procedures, and modeling for the characterization and measurement of site hydrology is presented in Appendix A, *Hydrology*.

The goal of this appendix is to outline the rationale and methods to characterize and monitor soil erosion and sedimentation. This appendix also outlines and discusses the design and effectiveness of control practices to minimize impacts to water quality and aquatic resources. This appendix includes reference sections of both cited literature and other relevant references. A reference by Barfield et al. (1981) provides an excellent compendium of both hydrologic methods, as well as methods to measure erosion and to design erosion control structures at mines. The reader is referred to this source for a detailed compendium of methods to measure erosion and design control measures to mitigate erosion and sedimentation at mines.

2.0 TYPES OF EROSION AND SEDIMENT TRANSPORT

Erosion is a natural geologic process that is easily induced and accelerated by man's activities. Mining activities can require the disturbance of large areas of ground and require large-scale earth moving activities which expose large amounts of soil to erosive forces. Operations can be planned, however, to minimize the amount of soil exposed and to reduce or prevent adverse effects on the streams or other water bodies from sedimentation.

Soil erosion can be defined as the detachment, transport, and deposition of soil particles. Detachment is the dislodging of soil particles from aggregates or soil peds from either rain drop impact or from the shearing forces of water or air flowing over the surface. Of these, rain drop impact is the primary force causing detachment, while the flow of water or air over the surface is the primary mechanism for transport. Rain drop splash can also be a cause of soil transport at a micro-scale (Maclean, 1997). Transport by runoff across the surface, therefore, does not generally occur until the rainfall rate exceeds the infiltration capacity of the soil. Once runoff occurs, the quantity and size of soil particles transported is a function of the velocity of the flow (Barfield et al., 1981). Transport capacity decreases with decreasing velocity causing deposition. As velocity decreases, the largest particles and aggregates are deposited first with smaller particles being carried down slope. Deposition, therefore, usually results in the size and density sorting of eroded soil particles, with increasingly smaller sized particles being deposited down slope or down stream. The deposition of detached soil in streams is often referred to as sedimentation.

2.1 Interrill and Rill Erosion

Erosion occurs on disturbed or exposed areas by either interill or rill erosion. Interill erosion is sometimes referred to as sheet erosion. The primary erosive force in interrill areas is rain drop impact, where increasing detachment and erosion rates occur with increasing drop size and drop velocity. Rills are small channels which form on the surface as a result of increasing amounts of runoff. By definition, rills can generally be removed by ordinary tillage equipment or from light grading. Larger channels are considered gullies (see Section 2.2). Detachment occurs in rills by the shear forces of flowing water in the rill. The number of rills and the amount of rill erosion increases as the slope or the amount of surface runoff increases. Interill erosion is the dominant process on shallower slopes. Surface roughness and soil cohesive properties are the primary factors in controlling the degree of interill and rill erosion that occurs from an exposed area. The amount of vegetation cover is the primary factor affecting surface roughness. Vegetation decreases the velocity of runoff across the surface and protects the soil from rain drop impact. Other measures can be employed to increase surface roughness and minimize erosion. These measures are discussed in Section 6.0, Best Management Practices.

2.2 Gully Erosion

Gullies can be either continuous or discontinuous channels that flow in response to runoff events. By definition, gullies differ from rills in that they cannot be removed by ordinary tillage or grading practices. Gullies may be a temporary feature by being erosively active, or in a state of "healing" where annual deposition within the gully is greater than the detachment and transport of eroded materials. Healing is usually caused by changes in land use that reduce the velocity of surface runoff, such as applying reclamation measures to increase surface roughness and promote infiltration. The physical process of erosion in gullies is essentially the same as that described for rills. Erosion in gullies occurs primarily from the shear forces of flowing water. Foster (1985), however, indicated that the amount of erosion from gullies is usually less than the amount that occurs from rills. This is because the amount of erodible particles are quickly removed from the gully channel, where rills are established on an actively eroding surface. Therefore, after initial formation, gullies usually serve as a principal transport mechanism for entrained soils. Gullies can form quickly during extreme events on denuded land and can rapidly expand both up and down slope (Maclean, 1997). In these cases, gullies temporarily serve as large sources of eroded soil and sedimentation to water bodies. Uncontrolled runoff and gully formation can be a large source of transported sediment at mine sites.

2.3 Stream Channel Erosion

Stream channels differ from gullies in that they are permanent channels that transport surface waters. Stream channels can be perennial, ephemeral or intermittent. In stable stream channels, erosion and deposition is controlled by the transport capacity of a given stream flow, which is, in turn, governed by the velocity of flow and by local variations in shear stress in the channel. Detachment and entrainment of soil particles will occur along the stream bed and sides of a channel when the transport capacity is greater than the sediment load being transported. Deposition occurs when the transport capacity is less than the sediment load being transported. As described in Section 2.0 above, deposition occurs from the largest to the smallest particles as velocity and transport capacity decrease. Potential impacts from mine related activities on channel erosion processes are discussed in Section 3.0.

2.4 Mass Wasting, Landslides and Debris Flows

Landslides and slope failures that create large areas of mass wasting can occur naturally or can be induced as a result of man's activities. The potential for landslides to occur generally increases in steep areas containing unstable soils or where the bedrock has unfavorable dip directions. Landslides and slope failures occur naturally over time, usually during extreme precipitation events when saturation reduces the shear strength of the soils or rock. Slope failures and landslides can also be induced by construction activities that create cuts or slopes where soils or rock are left exposed at steep, unstable angles.

Landslides can expose large areas of soil and debris that are subject to the erosion and sedimentation processes discussed above. Landslides can block stream channels with soil and rock debris, causing ponding and eventual flooding. The eventual failure of an unstable blockage can result in flood flows that entrain large quantities of soil and rock debris. Scouring of the existing channel below the landslide also results from the high flood flows. Additional debris loading can occur from mass wasting along the side slopes, adding more sediment and debris loads to the flood flow.

Effects from avalanches can be similar to those of landslides. Avalanches can remove vegetation, increasing the erosion potential of exposed soils and rock. Debris and snow from an avalanche can temporarily block stream channels, creating floods, channel scour, and mass wasting along side slopes.

Landslides, slope failures, and avalanches can create large impacts to aquatic resources. Increased erosion and resulting sedimentation within a watershed can impact spawning gravels, egg survival and emergence of frye, as well as degrade benthic food sources. Flooding can create high velocity flows, scour stream banks and destroy gravel substrates either by scour or by burial beneath sediment. Cover created by large woody debris and stable banks also can be destroyed, which impacts rearing and resting habitat for fishes.

3.0 MINING-RELATED SOURCES OF EROSION AND SEDIMENTATION

Increased potentials for erosion and sedimentation at mines are related to mine construction and facility location. Tailings dams, waste rock and spent ore storage piles, leach facilities, or other earthen structures are all potential sources of sedimentation to streams. Road construction, logging, and clearing of areas for buildings, mills, and process facilities can expose soils and increase the amount of surface runoff that reaches streams and other surface water bodies. These activities increase the potential for rill and interill erosion and can increase peak stream flows, increasing the potential for channel erosion. Unusually high peak flows can erode stream banks, widen primary flow channels, erode bed materials, deepen and straighten stream channels, and alter channel grade (slope). In turn, these changes in stream morphology can degrade aquatic habitats. Channelization can increase flow velocities in a stream reach, potentially affecting fish passage to upstream reaches during moderate to high stream flows. Poorly designed stream diversions can also create channelization effects and alter flow velocities in a stream. Increased erosion upstream and the resulting sedimentation downstream can impact spawning gravels, egg survival and emergence of frye, as well as degrade benthic food sources. More detail on these potential impacts is given in *Appendix A, Hydrology.* Tailings dams and large embankments can also fail, creating impacts similar to those discussed in Section 2.4 above for landslides and debris flows.

4.0 METHODS TO MEASURE AND PREDICT EROSION AND SEDIMENTATION

Most methods to measure, predict and control erosion and sedimentation have been developed by the agriculture industry. These methods concentrate on predicting gross erosion and sediment yield from disturbed areas or areas under tillage. This is advantageous for evaluating and predicting impacts that result from mining because tillage agriculture and mining have several similarities (Barfield et al., 1981). Both industries can disturb and expose large areas of ground and both must apply practices to limit or eliminate soil-loss and sedimentation impact. It should be noted, however, that many mine sites are often located on steeper slopes and in more diverse topography than agricultural lands. Methods developed for the measurement of erosion and sedimentation from agricultural lands are generally not adapted or tested for use on steep slopes. For this reason, appropriate conservatism should be applied when choosing analytical methods and in evaluating predictive results.

Most methods to measure or predict erosion and sedimentation are designed to predict either: (1) "gross erosion", (2) "sediment yield", (3) a "sediment delivery ratio", or (4) sediment loading in streams. Gross erosion is defined as the total estimated amount of sediment that is produced from rill and interill erosion in an area (Barfield et al., 1981). The sediment yield from an area or watershed is the gross erosion, plus the additional erosion that is contributed from gullies and stream channels, minus the amount of deposition. The amount of deposition that occurs between the watershed and a down-gradient point of reference is quantified using a sediment delivery ratio. A sediment delivery ratio can be quantitatively defined as the ratio of sediment yield to gross erosion:

$$D \; \frac{Y}{A}$$

where D is the sediment delivery ratio, Y is the sediment yield, and A is the gross erosion (Barfield et al., 1981).

Few methods have been developed to specifically predict gross erosion or sediment yield from undisturbed landscapes and watersheds. Methods for field measurement, as well as methods to analytically predict or model sediment yield are commonly employed on both disturbed and on undisturbed areas. For this reason, field and analytical methods that can be used to measure gross erosion or sediment yield on disturbed and undisturbed areas are outlined together in this appendix. This section summarizes methods to measure or predict gross erosion, methods to measure or predict sediment yield, including modeling, and methods to measure sediment loads and deposition in streams.

4.1 Gross Erosion

4.1.1 Field Measurements.

Few field methods are usually employed to measure the amount of gross erosion which actually occurs from a small plot or watershed. A method commonly used, however, is to use erosion pins. Using this method, small pins or stakes are put into the ground to a depth that will prevent disturbance. The elevation of the top of the pin is surveyed and referenced to a permanent elevation. The difference between the top of the pin and the ground elevation below the pin is periodically surveyed to determine minute changes in elevation. The difference in measured elevation between sampling events reflects the amount of rill and interill erosion that has occurred at that point. Gross erosion that occurs from a sample plot can be estimated using measurements from several pins. Repeated measurements of water and sediment collected in permanently installed hill slope troughs can also be used to detect soil movement and storage over time.

Tracers have also been used to detect and measure actual soil movement on small plots. Kachanoski et al. (1992) describe the use of Cesium-137 (^{137}Cs) to detect soil movement and soil loss in a complex landscape and to monitor the down-slope movement of soils that occur from tillage. ^{137}Cs occurs in soils from atmospheric deposition (fall out) that occurred from above-ground nuclear testing conducted in the 1950s and 1960s. ^{137}Cs tightly binds to soils, is essentially insoluble and does not leach, and is not subject to significant uptake by plants. Monitoring gains or losses of ^{137}Cs at permanent points can be used to detect movement of soil. Other inert tracers can be used similarly.

The above field methods are commonly employed for research purposes where actual land treatment applications or practices are compared. They are often employed to aid model validation or to help calibrate modeled soil losses from a specific area. While these methods can be used to detect soil movement and estimate gross erosion on small plots, they may not be applicable at mine sites because they are not suitable for large areas, and they do not predict sediment yield or sedimentation of streams or other water bodies.

4.1.2 The Universal Soil Loss Equation.

The most commonly used procedure to predict gross erosion is the Universal Soil Loss Equation (USLE), in its original form. The USLE was proposed by Wischmeier and Smith (1965) based on a relationship known as the Musgrave equation (Musgrave, 1947). The USLE predicts gross erosion produced by rill and interrill erosion from a field sized area. Several authors have proposed modifications to the USLE to account for deposition so the model can also be used to predict sediment yield. These modifications will be discussed in Section 4.2 with methods to measure and predict sediment yield. The USLE predicts gross erosion by the following:

$$A = R * K * LS * C * P$$

where, A is computed soil loss per unit of area (tons/acre), R is a rainfall factor which incorporates rainfall energy and runoff; K is soil erodibility; LS is a dimensionless length slope factor to account for variations in length and degree of slope; C is a cover factor to account for the effects of vegetation in reducing erosion; and P is a conservation practice factor. A detailed discussion of how to calculate, incorporate, and use each of these factors is provided by Barfield et al. (1981) and Goldman et al. (1986). The USLE can be used to predict gross erosion from an area for average annual, average monthly, average storm, and annual return period, or for a single storm return period, depending on how R is calculated.

Use of the USLE, without modification, at mine sites has several disadvantages. The calculation does not account for erosion from gullies, or stream channels, or take into account deposition. It was primarily designed to predict soil-loss from small fields and should not be used to predict sediment levels in rivers at the drainage basin level. For most applications at mine sites, the unmodified USLE described above would not provide useful estimates because most impact analyses require knowledge of deposition and actual sediment yield from watersheds or disturbed areas, and calculations of sediment transport in gullies and channels. Consequently, this method is not recommended, except for calculations of potential soil-loss from a small disturbed area to aid in the application of best management practices (BMPs) and the design of other area-specific controls.

4.2 Sediment Yield

Most methods and mathematical models to measure or predict erosion are designed to predict sediment yield from an area or watershed. Many of the methods and models use the USLE, described in Section 4.1.2, however, they incorporate techniques to evaluate and route erosion from gullies and channels and estimate deposition, either on the land surface or in streams. The following discussion provides a brief review of commonly used methods to measure sediment yield and presents a review of mathematical models which have been used to predict sediment yield on an areal or watershed basis.

4.2.1 Modified and Revised Universal Soil Loss Equation.

There have been several proposed modifications to the USLE that allow for more accurate predictions of parameters and erosion. For purposes of baseline characterization and prediction of sedimentation at mine sites, two modifications are applicable. The Modified Universal Soil Loss Equation (MUSLE) and the Revised Universal Soil Loss Equation (RUSLE). In the standard USLE model, the rainfall energy and runoff factor (R) and the length-slope factor (LS) do not account for deposition or assume that it does not occur until the end of the length of the ground segment being analyzed. Williams (1975) proposed that the R factor be replaced with several other terms to allow the equation to better account for deposition. This modification (MUSLE) can then be used to estimate the sediment yield from an area or from watersheds. The MUSLE equation is calculated by:

$$Y = 95(Q * q_{pi})^{0.56} * K * LS * P$$

where Y is the single storm sediment yield, Q is the runoff volume, q_{pi} is the peak discharge, and K, LS, and P are the same terms as for the USLE except that they represent weighted averages for these parameters, calculated from different areas of the watershed. The LS factor is also calculated differently than in the USLE, depending on the slope being analyzed (Williams, 1975). The RUSLE described by McCool et al. (1987) provides a further revision of the LS factor and modifies the model to be more applicable on steep slopes, greater than 10 percent.

The application of the MUSLE and the RUSLE to large, heterogeneous watersheds, such as those that occur at mine sites, requires that sediment yield calculations be analyzed for each subwatershed (see Williams (1975) and Barfield et al. (1981) for detailed discussions). The analysis requires that large, heterogeneous watersheds be divided into several subwatersheds with relatively homogeneous hydrologic characteristics and soil types. Consequently, particle size distribution (i.e., texture analysis) must be measured for the soils occurring in each subwatershed. The analysis also requires the calculation of a weighted runoff energy term ($Q^* q_{pi}$) that is computed as a weighted average of the subwatersheds. From particle size distribution data, the median (D_{50}) particle diameter is used to calculate the sediment yield that would exit each subwatershed. The weighed runoff energy term is used to route sediments to the mouth of the large watershed or at some point of analysis.

4.3 Suspended Load and Sedimentation

The evaluation of water quality and impacts to aquatic resources is a primary concern at mine sites. Without mitigation and control measures, mining can disturb large areas of ground, causing accelerated erosion and sedimentation and potentially causing adverse impacts to aquatic resources. The measurement of sediment load in streams is a primary tool to evaluate the effectiveness of erosion control measures and potential impacts to water quality and aquatic life. Typically, it is a required component for monitoring compliance with NPDES permits. As discussed in Section 2.3, the amount of sediment load being carried at any given time in a stream depends on the transport capacity, which is primarily related to the stream flow velocity. As transport capacity increases, the amount and particle sizes of suspended sediment increases. Transport capacity decreases with decreasing flow velocity, causing deposition and sorting of materials. The transport and deposition of sediments within a stream, therefore, dependent on storm frequency and the velocity of peak flows. In many cases, high flow events are periodically required to entrain and transport sediments that were deposited during low flow periods when low peak velocities caused sediment deposition. These are known as channel maintenance flows. Geomorphologically, a stable channel is one that over time, transport sediments with no net increase in deposition and without channel erosion.

The Equal Transient Rate (ETR) and Equal Width Increment (EWI) methods are commonly used field methods to sample suspended sediments during stream flow (USGS, 1960). Using these methods, several water samples are taken along cross-sectional transects (i.e., perpendicular to flow direction). Samples along the cross section are taken by lowering a sample bottle through the stream at a rate dependent on the flow velocity. The total mass of suspended sediment and its particle size distribution are measured for each sample. Automatic sediment samplers are also available that collect stream samples at scheduled times that are determined by the user. These data are used to develop a sediment rating curve or a sedigraph that defines the relationship between stream flow discharge (Q_w) and the mass of suspended sediment at a given sampling station. After a sediment rating curve has been developed, stream flow measurements can be used to estimate sediment discharge at a given station. Sediment rating curves and sedigraphs can be extremely useful for monitoring the effectiveness of control practices applied to minimize erosion and sediment yield from mine sites. The development of sediment rating curves, however, requires sampling across a large range of flows and at different seasons of the year. These relationships can be continuously recalibrated and refined as the size of the sampled data base increases.

Net increases in sediment deposition in streams and other water bodies are measured using substrate core samples at various times of the year. Core samples, taken using a variety of substrate and coring equipment, are analyzed for net changes in particle size distribution over time. It is important for water quality analyses at mines, that sampling programs to monitor sedimentation in stream beds incorporate comparisons with stream flow events. Regular sampling throughout the year is required to determine if net deposition of sediments is occurring in a stream over time. Sediments are naturally deposited during seasonal low flow periods and are naturally entrained and transported during high flow periods. These processes make impact analysis by sedimentation extremely difficult to monitor.

In addition to the above analyses, characterization of pre-mining stream morphology from drainages potentially affected by a mining operation are often necessary to determine potential impacts caused by changes in flow regime and from sedimentation. These analyses may include photo documentation of streams and riparian vegetation, determining geomorphological classifications of streams using the Rosgen (1994) method, and measurements to define channel cross sections, width to depth ratios, longitudinal profiles, sinuosity, and pool/riffle ratios. These data would support studies conducted to characterize site hydrology and aquatic resources.

4.4 Software and Watershed Models for Prediction of Sediment Yield

Characterization of mine sites requires the accurate calculation of sediment yield on a large watershed basis. To characterize baseline conditions at mine sites and to predict potential adverse impacts from sedimentation requires adequate spatial and areal characterization of gross erosion and sediment yield. Several analytical software programs are available to predict sediment yield and sediment transport in large watersheds. Some of these can be incorporated into GIS applications to provide spatial evaluation of erosion potential and sediment yield for one or more watersheds.

The MUSLE and RUSLE, applications described in Section 4.2.1 could be used to characterize baseline conditions of sediment yield and to evaluate potential changes in expected sediment yield that would result from development of mine facilities. Most software, watershed models, and GIS applications that are commonly used to predict erosion and sediment yield apply either the USLE, MUSLE, or RUSLE algorithms. A brief description of analytical software used for watershed analysis and for the evaluation of sediment yield is provided in Section 4.4.2. Particular emphasis is given to those methods that are commonly used in mine settings.

The following questions, modified from Maclean (1997), can be used to determine the type and level of modeling effort needed and software required to evaluate erosion and sedimentation at mine sites:

- What are the basic assumptions and method(s) applied in the model?
- Is the output suitable to make the evaluations and analyses required and is the accuracy sufficient for characterization, impact analysis, and detection monitoring?
- What are the temporal and spatial scales of the required analysis?
- What are the input data requirements of the software or model?
- What data are needed for model calibration and verification?
- Are the required data available and are they at the correct scale?
- What input data are the most important (i.e., have the most sensitivity)?
- Can surrogates be used for missing data without compromising an accurate analysis?
- If the model uses empirical (i.e., statistical) relationships, under what conditions were those formed?

Answering these questions will help the mining hydrologist to select appropriate techniques and models and to design adequate sampling programs to obtain the required input data. As previously discussed, to adequately evaluate and monitor impacts at mine sites typically require temporal and spatial analysis of a large watershed. This necessitates the design of a sampling programs that will provide adequate data on a watershed basis. Monitoring programs to evaluate erosion and sedimentation should be coordinated with baseline hydrological and water quality characterization studies. The reader is referred to Appendix A, *Hydrology* and Appendix B, *Receiving Waters* for related discussions.

4.4.1 Development of a Conceptual Site Model.

A conceptual site model can be used to expedite an evaluation of the questions and parameters discussed in Section 4.3. A conceptual site model is a depiction, descriptive, or pictorial, of subwatersheds, soil-types, slopes, stream channels and any erosional features. Such a model should be developed in conjunction with studies to characterize baseline soil and vegetation types and surface water bodies. The purpose of building or developing a conceptual model of a site is to show important interrelationships that need to be evaluated, studied, or modeled. Programs to analyze impacts and monitor site conditions can then be developed. The conceptual model should be complex enough to adequately depict system behavior and meet study objectives, but sufficiently simple to allow timely and meaningful development of field sampling programs and predictive models.

4.4.2 Analytical Software and Models.

AGNPS - Agricultural Non-Point Source Pollution Model

AGNPS is a distributed river basin model which combines elements of several other models to predict erosion, runoff, and sediment and chemical transport. The model incorporates the USLE to predict gross erosion from defined grids within a the river basin. Runoff and overland flow is calculated using Natural Resource Conservation Service (NRCS [Soil Conservation Service]) procedures (see Appendix A, *Hydrology).* Transport and deposition relationships are used to determine sediment yields and route sediment through the modeled basin. The program is designed for large basins and requires very detailed site characterization data for input. The level of accuracy necessary for the prediction of sediment yield and transport at mine sites would require detailed field sampling to provide input data. The model has the inherent problems associated with the USLE, described in Section 4.1.2, and problems associated with the SCS hydrologic methods to predict runoff (See Appendix A , *Hydrology*). The assumptions of the USLE and the SCS methods should be completely understood when using this model for predictive purposes. A review of this model is provided by Jakubauskas (1992).

ANSWRS - Areal Non-Point Source Watershed Response Simulation Model

ANSWRS is a distributed river basin model that is similar to the AGNPS model. The model uses the USLE to predict the upland component for gross erosion and a set of steady state equations to simulate sediment transport through the basin. A review of this model is provided by Jakubauskas (1992). Both the ANSWRS and AGNPS models are designed to evaluate erosion and plan control strategies on areas with intense cultivation.

WEPP - Water Erosion Prediction Project Hydrology Model

WEPP is designed to use soil physical properties and meteorological and vegetation data to simulate surface runoff, soil evaporation, plant transpiration, unsaturated flow, and surface and subsurface drainage. The model uses the Green and Ampt infiltration equation to estimate the rate and volume of storm excess precipitation. Excess precipitation is routed downslope to estimate the overland flow hydrograph using the kinematic wave method. In WEPP, surface runoff is used to calculate rill erosion and runoff sediment transport capacity. The infiltration equation is linked with the evapotranspiration, drainage, and percolation components to maintain a continuous daily water balance for a watershed.

HEC-6 - Scour and Deposition Model

HEC-6 is designed to evaluate long-term river and reservoir sedimentation behavior. The program simulates the transportation of sediment in a stream and can determine both the volume and location of sediment deposits. It can analyze in-stream dredging operations, shallow reservoirs, and scour and deposition effects in streams and rivers, in addition to the fall and rise of movable bed material during several flow cycles. The program is primarily designed to analyze sediment transport and geomorphologic effects in rivers and streams. It is not intended for use in analyzing gross erosion or sediment yield from watersheds.

Sedimont-II - Hydrology and Sedimentology Model [1]

Sedimont-II is designed to generate and route hydrographs and sediment loads through multiple subareas, reaches and reservoirs. It can also be used to evaluate the effectiveness of sediment detention ponds and grass filters. The program can predict peak sediment concentration from a flow event, trap efficiency of a sediment retention basin, sediment load discharge, peak effluent sediment concentration, and peak effluent settleable concentration.

SEDCAD+ [2]

SEDCAD+ provides computer-aided design (CAD) capabilities for the design and evaluation of storm water, erosion, and sediment control management practices. The software combines hydrological and sediment yield modeling with CAD capabilities to design and evaluate the performance of sediment detention basins, channels, grass filters, porous rock check dams, culverts and plunge pools. In addition, the program provides determinations of land volumes, areas, and cut/fill volumes. The program uses the MUSLE and RUSLE algorithms to calculate sediment yield from watersheds. The software has used as a part of the Office of Surface Mining's Technical Information Processing System (TIPS). TIPS is a series of integrated programs to provide automated software to support a full range of engineering, hydrological, and scientific applications required for permitting.

PONDPACK [1]

PONDPACK is designed to provide CAD capabilities for the design and evaluation of storm water detention ponds. The program provides analysis of detention storage requirements, computes a volume rating table for pond configuration, routes hydrographs for different return frequencies, and provides routing data for inflow and outflow hydrographs for comparing alternative pond designs.

[1] Haestead Methods, Waterbury, Connecticut.

[2] Civil Software Design, Ames, Iowa

4.4.3 Application of Remote Sensing and Geographical Information Systems (GIS).

Recent research has evaluated the use of Geographical Information Systems (GIS) and data obtained from satellites in predictions of large-scale erosion potential. Example studies are provided by MacLean (1997) and DeRoo et al. (1989); other references are provided at the end of this appendix. In general, GIS systems can be used to provide spatial data for soil-types, vegetation cover types, aspect, slope, slope-lengths, and other variables that are required inputs for large-scale watershed models. These data may bes incorporated or estimated using remotely sensed data obtained from SPOT or LANDSAT imagery. Modeled data can also be presented and analyzed using a GIS system as demonstrated by the studies referenced above, which incorporated spatial data into large-scale, river basin models that evaluated erosion potential and prediction using the USLE. In general, these studies showed that a GIS system could be used to manage, provide and evaluate large amounts of spatial data in conjunction with erosion modeling. These studies, however, indicated that model accuracy and validation were deficient because specific site data were not available or had to be assumed. DeRoo et al. (1989) suggested that model accuracy is extremely sensitive to the "lack of detailed" input data such as infiltration capacities, antecedent soil moisture, and rainfall intensity information for specific sites. MacLean (1997) indicated that confidence in the results generated using GIS was low.

These studies indicate that large, spatially integrated systems could be used at mine sites for baseline characterization and analysis of impacts. However, mining hydrologists and other scientists must be aware that specific information regarding soil-types, soil particle size analysis, vegetation types, slopes, slope-lengths, and sub-basin hydrology are required to produce accurate erosion and sedimentation analyses. Caution should be used when integrating spatial data bases with predictive modeling in cases where site-specific data are inadequate.

5.0 REPRESENTATIVENESS OF DATA

The representativeness of data and statistical concepts related to sampling and the development of data quality objectives are discussed in detail in *Appendix A, Hydrology.* In general, the principles associated with sample adequacy, statistical techniques and the development of Quality Assurance programs for erosion and sedimentation are similar to those associated with hydrological measurements. A detailed discussion of these concepts is not repeated herein; the reader is referred to Appendix A for a discussion of statistical techniques and important parameters to consider in developing adequate sampling designs. Several concepts related to the measurement of erosion and sedimentation should be considered when developing Data Quality Objectives and sampling programs. The following points provide specific concepts which should be applied or noted in developing programs for monitoring erosion and sedimentation at mine sites:

- The processes of gross erosion, sediment yield, and sediment deposition in streams depends on the frequency and probability of hydrologic events, both seasonally and on an event basis. The amounts of sediment erosion, transport, and deposition vary seasonally and in response to individual precipitation-runoff events of different frequencies. For this reason characterization and monitoring programs at mine sites must be designed to evaluate erosion and sediment yields with respect to the frequency of storm events, as well as account for both seasonal and annual climatic variations. Similarly, characterization and monitoring programs to evaluate suspended loads in streams must take into account stream discharge measurements. Impact analysis can only be conducted if adequate relationships are developed between precipitation and runoff, stream flow, and sediment load.
- The effectiveness and accuracy with which mathematical models and empirical equations predict gross erosion, sediment yield, and sediment deposition depends on the quality of site-specific data collected to characterize soils, vegetation types, slopes, slope-lengths, and other watershed or subwatershed parameters. Of specific importance is that the samples collected to determine the particle size distributions (i.e., texture) of each soil type provide a statistically adequate population. Adequate sampling to characterize vegetative cover and other surface roughness factors controlling soil detachment and water flow velocities is also essential.
- The use of spatial data and GIS analyses should be encouraged to evaluate and predict potential impacts on a watershed basis. These analyses can be used to develop maps and provide spatial analyses of areas susceptible to erosion. As discussed in Section 4.4.3, however, the accurate prediction of erosion and sedimentation on a large-scale depends on having adequately characterized site-specific data.

6.0 METHODS TO MITIGATE EROSION AND SEDIMENTATION

Best Management Practices (BMPs) are schedules of activities, prohibitions of practices, maintenance procedures, and other management practices that effectively and economically control problems without disturbing the quality of the environment. Erosion and sedimentation may be effectively controlled by employing a system of BMPs that target each stage of the erosion process. Fundamentally, the approach involves minimizing the potential sources of sediment from the outset. In order to accomplish this, BMPs are designed to minimize the extent and duration of land disturbance and to protect soil surfaces once they are exposed. BMPs are also designed to control the amount and velocity of runoff and its ability to carry sediment by diverting incoming flows and impeding internally generated flows. BMPs also include the use of sediment-capturing devices to retain sediment on the project site. The types of BMPs discussed in this appendix include surface stabilization procedures, runoff control procedures and conveyance measures, outlet protection procedures, sediment traps and barriers, and stream protection procedures. Table H-1 provides an outline, by categorical type, that are used at mine sites. Sections 6.1.1 through 6.1.5 provide brief descriptions of these BMPs. Many of the BMPs are complementary and are used together as part of an erosion control program.

An important BMP used at mine sites to capture, manage and control sedimentation is the use of *Sediment Detention Basins.* Section 6.1.6 describes detention basins and discusses important design parameters for these basins at mine sites.

Table H-1. Mining BMPs for Control of Erosion and Sedimentation

Category	Best Management Practice
Surface Stabilization	Dust control Mulching Riprap Sodding Surface roughening Temporary gravel construction access Temporary and permanent seeding Topsoiling
Runoff Control and Conveyance Measures	Grass-lined channel Hardened channel Paved flume (chute) Runoff diversion Temporary slope drain
Outlet Protection	Level spreader Outlet stabilization structure
Sediment Traps and Barriers	Brush barrier Check dam Grade stabilization structure Sediment basin/rock dam Sediment trap Temporary block and gravel drop inlet protection Temporary fabric drop inlet protection Temporary sod drop inlet protection Vegetated filter strip
Stream Protection	Check dam Grade stabilization structure Streambank stabilization Temporary stream crossing
Source: NCSU Water Quality Group (1998).	

6.1 Best Management Practices (BMPs) Categories

The following discussion of Best Management Practices is adapted from NCSU Water Quality Group (1998).

6.1.1 Surface Stabilization Measures.

Dust Control is the manipulation of construction areas through specific measures to prevent soil loss as dust. Effective control measures include watering, mulching, spriging, or applying geotextile materials. These measures are designed to minimize the contamination of runoff water from air born dust. These practices are especially effective in regions with a dry climate or in drier seasons.

Mulching is the protection of vegetative surfaces with a blanket of plant residue or synthetic material applied to the soil surface to minimize raindrop impact energy, increase surface roughness and reduce the velocity of runoff. These practices are designed to foster vegetative establishment, reduce evaporation, insulate the soil, and suppress weed growth. As well as providing immediate protection from environmental hazards, mulch is used as a matrix for spreading plant seeds.

Riprap is a retention wall of graded stone underlain with a filter blanket of gravel, sand and gravel, or synthetic material designed to protect and stabilize areas which are prone to erosion, seepage, or poor soil structure. Riprap is used in areas where vegetation cannot be established to sufficiently reduce or prevent erosion. This includes channel slopes and bottoms, storm water structure inlets and outlets, slope drains, streambanks and shorelines.

Sodding is the continuous covering of exposed areas with rolls of grass to provide permanent stabilization. This procedure is especially useful in areas with a steep grade, where seeding is not conducive. As with mulching, sodding fosters vegetation growth, minimizes raindrop impact energy, increases surface roughness and reduces the velocity of runoff.

Temporary Gravel Construction Access is a graveled area or pad on which vehicles can drop their mud and sediment. By providing such an area, erosion from surface runoff, transport onto public roads, and dust accumulation may be avoided. This BMP is designed to capture potentially exposed sediment sources so they may be further managed and controlled.

Temporary and Permanent Seeding involves planting areas with rapid-growing annual grasses, small grains, or legumes to provide stability to disturbed areas. Areas are temporarily seeded if the soils are not to be brought to final grade for more than approximately one month. Permanent seeding is established on areas which will be covered with vegetative growth for more than two years. This BMP establishes a relatively quick growing vegetative cover.

Topsoiling is the application of loose, rich, biologically active soil to areas with mildly graded slopes. Often, facilities will stockpile topsoil for future site use. To ensure that runoff contamination does not occur, sediment barriers and temporary seeding should be used.

6.1.2 Runoff Control and Conveyance Measures.

A *Grass-Lined Channel* is a dry conduit vegetated with grass. Grass channels are used to conduct storm water runoff. In order for this system to function properly, the grass must be w-established and rooted before flows are introduced. Lining of the channels is required if design flows are to exceed 2 cubic feet per second (cfs). A grass channel increases shear stress within the channel, reduces flow velocities and promotes the deposition of sediments in storm water. The channel itself is also protected from erosion of the bed and sides.

Hardened Channels are conduits or ditches lined with structural materials such as riprap or paving. These channels are designed for the conveyance, transfer, and safe disposal of excess storm water. These channels are often used in places with steeply graded slopes, prolonged flow, potential for traffic damage, erodible soils, or design velocity exceeding 5 cfs.

Paved Flumes are concrete-lined conduits that are set into the ground. Flumes are used to convey water down a relatively steep slope without causing erosion. This system should have an additional energy dissipation feature to reduce erosion or scouring at the outlet. Flumes also should be designed with an inlet bypass that routes extreme flows away from the flume.

Runoff Diversions are temporary or permanent structures which channel, divert or capture runoff and transport it to areas where it can be used or released without erosion or flood damage. The types of structures used for this purpose include graded surfaces to redirect sheet flow, dikes or berms that force surface runoff around a protected area, and storm water conveyances which intercept, collect, and redirect runoff. Temporary diversion may be constructed by placing dikes of spoil materials or gravel on the down-gradient end of an excavated channel or swale. Permanent diversions, which are built to divide specific drainage areas when a larger runoff flows are expected, are sized to capture and carry a specific magnitude of design storm.

Temporary Slope Drains are temporary structures constructed of flexible tubing or conduit which convey runoff from the top to the bottom of a cut or fill slope. In conjunction with diversions, these drains are used to convey concentrated runoff away from a cut or fill slope until more permanent measures, such as stabilization with vegetation, can be established.

6.1.3 Outlet Protection.

Level Spreaders are a type of outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope. The landscape of the receiving area must be uniformly sloped, the outlet lip leveled, and the land unsusceptible to erosion. To avoid the formation of a gully, hardened structures, stiff grass hedges, or erosion-resistant matting should be incorporated into the design. This type of outlet is often used for runoff diversions.

Outlet Stabilization Structures are outlets that reduce outlet flow velocity and dissipate flow energy. These types of structures are used at the outlet of a channel or conduit where the discharge velocity exceeds that of the receiving area. The most common designs are riprap-lined aprons, riprap stilling basins, or plunge pools.

6.1.4 Sediment Traps and Barriers.

Brush Barriers are temporary sediment barriers that are constructed to form a berm across or at the toe of a slope susceptible to interill and rill erosion. They may consist of limbs, weeds, vines, root mats, rock, or other cleared materials.

Check Dams are temporary, emergency, or permanent structures constructed across drainageways other than live streams where they are used to restrict flow velocity and reduce channel erosion. In their permanent application, these dams gradually accumulate sediment until they are completely filled. At that point, a level surface or delta is formed into a non-eroding gradient over which the water cascades to a dam through a spillway into a hardened apron. Other alternatives for protecting channel bottoms should be evaluated before selecting the check dam on a temporary basis. Dams may either be porous or nonporous. Porous dams will decrease the head of flow over spillways by releasing part of the flow through the actual structure.

Grade Stabilization Structures are designed to reduce channel grade in natural or constructed channels to prevent erosion of a channel caused by increased slope or high flow velocities. This type of structure includes vertical-drop structures, concrete or riprap chutes, gabions, or pipe-drop structures. In areas where there are large water flows, concrete chutes or vertical-drop weirs constructed of reinforced concrete or sheet piling with concrete aprons are recommended. For areas with small flows, prefabricated metal-drop spillways or pipe overfall structures should be used.

*Sediment Detention Basin*s can be either permanent pool or self dewatering (i.e., complete flow through) types. They are primarily designed to allow ponding of runoff or flows so eroded soils and sediments can settle out and be captured before they can enter streams or other water bodies. The design and use of these basins is perhaps the most important BMP applied to control erosion at mine sites. Section 6.2 provides a detailed discussion of important design and management considerations for Sediment Detention Basins.

Sediment Fence (Silt Fence)/Straw Bale Barriers are temporary measures used to control sediment loss by reducing the velocity of sheet flows. They consist of filter fabric buried at the bottom, stretched, and supported by posts, or straw bales staked into the ground. Overflow outlets and sufficient storage area need to be provided to control temporary ponding.

Sediment Traps are small, temporary ponding basins formed by an embankment or excavation. These are less permanent structures than sediment detention basins. Outlets of diversion channels, slope drains, or other runoff conveyances that discharge sediment-laden water often use this system. Sediment traps should be designed to minimize the potential for short citcuiting, include features such as embankment protection and non-erosive emergency bypass areas, and provide for periodic maintenance.

Temporary Block and Gravel Inlet Protections are control barriers made of concrete block and gravel around a storm drain inlet. These structures filter sediment from storm water entering the inlet before soils have stabilized, while allowing the use of the inlet for storm water conveyance.

Temporary Excavated Drop Inlet Protections are temporary excavated areas around a storm drain inlet or curb designed to trap sediment. By trapping sediment before its entry into the inlet, the permanent inlet may be used before soils in the area are stabilized. This system requires frequent maintenance and can be used in combination with other temporary measures.

Temporary Fabric Drop Inlet Protections are fabric drapes placed around a drop inlet, on a temporary basis, during construction activities to protect storm drains. This practice can be used in combination with other temporary inlet protection devices.

Temporary Sod Drop Inlet Protection is a grass sod sediment filter area around a storm drain drop inlet. This is used when soils in the area are stabilized, and is suitable for the lawns of large buildings.

Vegetated Filter Strips (VFS) are natural or planted low-gradient vegetated areas consisting of relatively flat slopes which filter solids from overland sheet flow. Dense-culmed, herbaceous, erosion-resistant plant species are appropriate for vegetating these strips. The effectiveness VFSs is increased, if channelized flows are absent; however, the main factors influencing removal efficiency are vegetation type and condition, soil infiltration rate, and flow depth and travel time. Level spreaders are often used to promote even distribution of runoff across the VFS.

6.1.5 Stream Protection.

Check dams, grade stabilization structures, and streambank stabilization techniques are also BMPs used for stream protection. An additional stream protection BMP is a *Temporary Stream Crossing.* These crossings may be in the form of a bridge, ford, or temporary structure installed across a stream or watercourse for short-term use by construction vehicles or heavy equipment. Wherever possible, bridges should be constructed in lieu of other types of stream crossings, because they cause the least damage to streambeds, banks, and surrounding floodplains, provide the least obstruction to flow, and have the lowest potential to increase erosion . Culvert crossings are the most common and are the most destructive form of crossings. Culverts generally cause significant impacts to a stream bed and increase the potential for channel scour. Low-span bottomless arched conduits offer the simplicity of a culvert crossing and minimize impacts to the stream bed. These crossings can be placed over the top of stream channels without disturbing the streambed at the crossing. Fords are cuts in the banks with filter cloth held in place by stones. They are used in steep areas prone to flash flooding, but should be used only where crossings are infrequent and banks are low. Another technique which can be applied is to size a main culvert to handle normal bankfull flows. Additional culverts are then placed along side of the main culvert at a higher elevational base. The additional culverts route flood flows that exceed the capacity of the main culvert and would normally move out across a floodplain. The advantage to this design is that overly sized culverts can often cause channelization, increases in flow velocity and scouring of the channel down stream. A multi-culvert design reduces these effects by sizing the main culvert to handle normal stream flows. All stream crossings should be located on a permanent basis to prevent overtopping and minimize erosion potential.

6.1.6 Sediment Detention Basins.

Sediment detention basins are commonly used to prevent or control sediment deposition in streams and water bodies (Barfield et al., 1981). Detention basins are designed to capture runoff or conveyed storm water and reduce water velocity to allow sediments to settle out. Storm flows eventually pass through an outflow structure leaving the sediment (i.e., settleable solids) in the basin.

Detention basins must be designed to account for several storage volumes including: (1) a sediment storage volume (V_s); (2) a storage volume for detention storage (V_d); (3) and a final flood storage volume (V_f). The design storage for V_s depends on the loading and volume of sediment that would be expected for a specific design period. The design period can be the life of the mine, or a shorter period in which accumulated sediments are periodically dredged or removed from the detention basin. Estimates for V_s are made using the methods or models to predict expected sediment yields entering the basin (see Section 4.2). In general, the USLE or the MUSLE are used to calculate sediment loading to a detention basin, either on an annual or a design storm basis. V_d is the storage volume that is required to detain and hold the volume of runoff from a specified design storm long enough to allow the sediment to settle out. A variety of methods are used to calculate storm runoff volume (V_f) (see Appendix A, *Hydrology)*. V_f is the final flood storage volume or free board which is added as contingency to prevent overtopping and dam failure during extreme events that exceed the design capacity.

Sediment detention basins are designed to maximize trap efficiency in order to minimize the release of suspended loads downstream at mine sites. Trap efficiency is defined as the ratio between the mass of sediment flowing into a basin and the mass of sediment flowing out of a basin. Barfield et al. (1981) outline several parameters that affect the performance and trap efficiency of a basin:

- Particle size distribution of sediments
- Detention storage time
- Reservoir shape, amount of dead storage, and turbulence
- Water chemistry
- The use of flocculants

Because sediment detention basins are usually flow-through structures, trap efficiencies are optimized by setting design criteria or goals that maximize the capture of all settleable solids for a given design storm (i.e., storm frequency). At mine sites, it is common practice to design sediment detention basins based on the 10-year, 24-hour precipitation event. This design standard is based on the criteria for exemption for discharge of excess storm water at mine sites.

The particle size distribution sediments flowing into a detention basin is the single most important factor affecting trap efficiency (Barfield et al., 1981), because particle size is directly related to settling velocity. Assuming steady-state flow through a reservoir, a decrease in particle or aggregate size requires an increased flow length to allow a particle to settle out. For this reason, accurate characterization of particle size distributions of potentially incoming sediments is critical to pond design and management.

The detention storage time is the volume-weighted average time that a volume of flow will be detained in a reservoir. The detention time of a settling basin is a function of basin shape, basin length and the design of the outlet structure. The design of the outflow structure determines the characteristics of the outflow hydrograph and its relationships to the inflow hydrograph.

Basin shape strongly influences how effectively the storage volume of the basin is used for sedimentation. The basin shape determines flow path length, flow velocity, areas of turbulence within the basin, and if dead storage areas occur. Small localized zones of turbulence within the basin can inhibit particle settling because of locally increased flow velocities. Dead storage areas are zones within the basin that are bypassed and, therefore, ineffective in the settling process. EPA (1976) suggests that dead storage volume can be minimized by maintaining a 2:1 ratio between reservoir length (i.e., the length of the flow path) and reservoir width.

Water chemistry also affects particle settling and trap efficiency. In general, the ionic strength of the water is a primary factor affecting particle flocculation or dispersion. Flocculation of particles to larger, heavier aggregates generally increases with increased ionic strength. The types of cations present, however, also affect this process. Because they are divalent, calcium and magnesium cations tend to be very effective in increasing flocculation. Effects of ionic strength on flocculation and dispersion can be specifically related, therefore, to the relative concentrations of these cations in solution. The Exchangeable Sodium Percentage (ESP) and the Sodium Absorption Ration (SAR) are useful parameters that should be examined when evaluating the effects of water chemistry (Barfield et al., 1981).

Flocculant, which are compounds that enhance the aggregation of particles, often are used to aid the performance of a detention basin and, in some cases, to ensure that water quality standards are met at the basin outlet. Flocculants create larger particles that have greater settling velocities. They can be particularly useful when a large proportion of entrained sediment are clay, fine silt, or colloidal materials. Colloidal particles remain in suspension and will not settle out even under quiescent conditions. Barfield et al. (1981) provides a detailed discussion on water chemistry, flocculation and the design of programs in enhance settling using flocculants in sediment detention basins.

CAD and modeling software usually is employed to design sediment detention basins. In particular, SEDCAD+, PONDPACK, and SEDIMONT II, described in Section 4.3.2, are specifically used to apply both hydrologic and erosion measurements to the design of sediment detention basins. Using these types of software, a hydrologist can iteratively design detention basins to optimize basin size and shape, detention storage time, and the type of outflow structure required to meet design criteria. These models provide analyses of both inflow and outflow hydrographs and inflow and outflow sedigraphs. Analyses are performed to provide estimates of trap efficiency, mass of settleable solids captured, and mass of suspended solids not retained by the basin. Basins designed using software packages depend on accurate input data for hydrologic and soil variables. In particular, accurate information regarding soil types and particle size distributions (texture) are necessary for accurate design.

6.2 Innovative Control Practices

Most erosion and sediment control BMPs have been standard practice for many years. As discussed in Section 6.1, standard BMPs include surface stabilization measures, diversions and channels, and sediment traps and barriers. Some innovative BMPs, however, include variations of these practices that offer particularly effective controls. These practices include:

- The design and construction of artificial wetlands to provide natural filtration and enable sediment deposition. Artificial or constructed wetlands can effectively remove suspended solids, particulates and metals attached to sediments through the physical processes of velocity reduction, filtration by vegetation, and chemical precipitation as water flows through the wetlands.
- The use of geotextiles for soil stabilization and erosion control blankets and mattings. Geotextiles can be made of natural or synthetic materials and are used to temporarily or permanently stabilize soil. Synthetic geotextiles are fabricated from non-biodegradable materials and are generally classified as either Turf Reinforcement Mats (TRMs) or Erosion Control and Revegetation Mats (ECRMs). TRMs are three-dimensional polymer nettings or monofilaments formed into a mat to protect seeds and increase germination. ECRMs are composed of continuous monofilaments bound by heat fusion or stitched between nettings. They serve as a permanent mulch.
- Biotechnical stabilization techniques that use layers of live brush to help stabilize slopes. Biotechnical stabilization can control or prevent surface erosion and mass slope failures. This technique involves the use of cut branches and stems of species such as willow, alder and poplar. The live brush is embedded into the ground in a criss-cross pattern so that roots and shoots will eventually develop. Biotechnical stabilization is most effective when shrubs are cut and utilized during dormant periods.

7.0 SUMMARY

Mining activities have the potential to expose large areas of soil and rock to the processes of erosion. Mine pits, roads, tailings dams, waste rock and ore piles, and other facilities are potential sources of sediment that can be transported and deposited in streams and other water bodies. If properly planned and managed, however, adverse impacts to water quality and aquatic resources can be minimized or prevented. To prevent potential impacts, water and sediment management needs to be considered from the beginning of any mining plan.

The development of an effective erosion control plan must start with accurate baseline characterization of erosion and sediment potentials on a watershed basis. Accurate knowledge of existing conditions is necessary to design and implement effective erosion control programs and to allow accurate monitoring for impacts. Baseline characterization depends on sampling programs that adequately determine existing soil types and their particle size distributions, existing vegetation types and cover values, slopes and slope lengths, as well as the relationships between existing drainages and stream channels. Programs to characterize baseline water quality must take into account variations in stream flow. This includes variations that occur on a storm basis, as well as on a seasonal or annual basis. Developing monitoring programs that accurately detect or evaluate impacts and control effectiveness depends on having accurate knowledge of natural erosion and degradation rates and patterns.

The choice of methods to predict gross erosion and sediment yield from natural or disturbed areas may be dependent on the type of input data required. It is very important that the mining hydrologist understands all assumptions inherent in a model or method when conducting analyses to predict sediment yields or design erosion controls. Accurate analyses by available software programs and models requires accurate site-specific sampling for input data. Vegetation parameters, soil types, and soil particle size distributions are, perhaps, the most important parameters that are input to predictive models and CAD programs.

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